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Protected areas, household environmental incomes and well-being in the Greater Serengeti-Mara Ecosystem

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ABSTRACT

Protected areas are an important cornerstone in the attempt to halt habitat and species losses. While it is widely recognized that local communities impact on conservation outcomes, there is a limited understanding of the economic importance of environmental resources in protected areas to local household incomes and well-being. This inhibits the development and implementation of efficient conservation policies. This paper, using the iconic case of the Greater Serengeti-Mara Ecosystem and its surrounding local communities in Tanzania and Kenya, quantifies the household-level economic importance of this protected area. Data was collected using well-being and environmentally augmented structured household surveys administered to 985 randomly selected households in 25 communities. Results documented high reliance on environmental income of the poorest, a negative relationship between environmental reliance and well-being, with households closer to the protected area having higher environmental reliance and lower well-being. Hence, degradation of protected area habitats will negatively and disproportionately affect the income and may further reduce the well-being of the poorest households. Sustainable protected area management must address human well-being as well as conservation objectives. Increasing access to education and building skills to promote alternative non-environmental based livelihood activities will promote both conservation and development objectives.

1. Introduction

Protected areas are designed to conserve natural habitats and species, by imposing restrictions on human activities. Protected areas are often subject to mounting pressure from nearby communities, especially in low income countries in locations where household income partially relies on resources within protected areas leading to conflicts between conservation and development (Chao et al., 2018; Hampson et al., 2015; Knapp et al., 2015; Wittemyer et al., 2008). This suggests that conservation in protected areas can benefit from an improved understanding of the compositions of local incomes and the determinants of well-being (MA, 2005; Wells and McShane, 2004), in particular in relation to the harvest of environmental products. Environmental products are harvested from non-cultivated habitats, including forests, grass-, bush- and wetlands, and fallows (PEN, 2007b) and include products such as firewood, timber, bushmeat, medicinal plants, and wild foods.

A global comparative study covering 7978 rural households in 24 countries across Latin America, Asia, and Sub-Saharan Africa estimated that an average of 28% of total annual household income originated directly from such products (Angelsen et al., 2014). Here we use the term environmental income to define the sum of such cash and subsistence income. Poor households tend to rely most on environmental income (as a percentage of their total household income, commonly called environmental reliance), whereas wealthier households tend to generate higher absolute environmental income (Angelsen et al., 2014; Vedeld et al., 2007). This pattern suggests that poorer households may be disproportionally negatively affected by habitat degradation, while wealthier households exercise higher pressure on environmental resources. However, quantification of the economic importance of environmental products to households living in and around protected areas is sparse (Chao et al., 2018; Kalaba et al., 2013; Rayamajhi et al., 2012; Silvestri et al., 2013; Summers et al., 2012; Wenny et al., 2011), with few a studies reporting high environmental reliance in the vicinity of protected area.

Recent investigations of environmental reliance have proceeded to capture poverty dynamics by incorporating asset analysis (Charlery and Walelign, 2015; Dokken and Angelsen, 2015; Nielsen et al., 2012) and

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following households over time (Waleligon et al., 2017). No studies, however, have yet combined analyses of environmental income with well-being. Well-being reflects the satisfaction of human needs and the associated life quality (Gough et al., 2007; Yang et al., 2013a). While well-being is an evolving concept and difficult to define and measure (Butler and Oluoch-Kosura, 2006), there has been recent progress. The Millennium Ecosystem Assessment (MA) has developed a conceptual framework for understanding the relationships between ecosystem services and human well-being, encompassing five components: “Basic Material for a Good Life”, “Security”, “Health”, “Good Social Relations”, and “Freedom of Choice and Action” (MA, 2003). Yang et al. (2013a) build on this to develop a human well-being index based on self-evaluation of satisfaction within each of the components, and an index of human dependence on ecosystem services (Yang et al., 2013b). However, evaluations of the relation between ecosystem services reliance and well-being remain scarce (Butler and Oluoch-Kosura, 2006). There are, to the best of our knowledge, yet no studies on the relationship between environmental income and well-being adjacent to protected areas.

Despite the unique conservation value of the world-renowned Greater Serengeti-Mara Ecosystem and its substantial contribution to regional and national economies through tourism (Sekar et al., 2014), there is little information about environmental income and its relationship with human well-being in the area. Local harvesting of environmental products is a source of conflict (Dobson, 2009) but environmental reliance remains unquantified. This study quantifies total household incomes, including environmental income, examines environmental reliance patterns and determinants across the study area, and investigates the relationship with human well-being. Specifically, we test four hypotheses: (1) Environmental reliance is inversely related with total household income; (2) Absolute environmental income is positively associated with total household income; (3) Well-being is inversely related with environmental reliance; and (4) Distance to the protected area boundary is negatively associated with absolute environmental income and reliance but positively associated with well-being. Hypotheses 1 and 2 are tested through plots against income quintiles and multivariate regression analysis using various indicators of wealth while controlling for relevant socioeconomic covariates. Hypothesis 3 is tested through plots of the relationship between well-being and environmental reliance and by regressing environmental reliance on well-being while controlling for relevant covariates. Hypothesis 4 is tested by including distance to the nearest protected area boundary in the models predicting absolute environmental income and reliance, and well-being. Including relevant socioeconomic control variables furthermore enables us to explore their significance and direction of influence in determining the outcome variables of interest.

2. Theoretical framework and concepts

2.1. Theoretical framework

The study is theoretically grounded in the conceptual framework of the Millennium Ecosystem Assessment and theories about sustainable rural livelihoods (Ellis, 2000; MA, 2003; Scoones, 1998; Winters et al., 2001) (Fig. 1). Both local communities and protected areas are key components in this framework. In this paper, we focus on incomes as the outcome of assets and capabilities, drawing on the Sustainable Livelihoods Framework, and Millennium Ecosystem Assessment work on human well-being to guide our empirical data collection and analysis. We make use of the Poverty and Environment Network (PEN) technical guidelines to develop and structure our data collection instruments (PEN, 2007b).

2.2. Concepts and definitions applied

Ecosystem services are benefits obtained by people from ecosystems contributing directly or indirectly to human well-being, encompassing provisioning, regulating, cultural, and supporting services (MA, 2005; TEEB, 2010). Here our focus is on provisioning services, specifically on household environmental income defined as the monetary cash and subsistence value of consumptive use of environmental resources. Human well-being is measured as satisfaction in five dimensions: “Basic Material for a Good Life”, “Security”, “Health”, “Good Social Relations”, and “Freedom of Choice and Action”, with each dimension investigated using four to seven indicators (MA, 2003; Yang et al., 2013a). Environmental income consists of subsistence and cash income from environmental goods, wage from natural resource-based activities, and direct transfer payments for environmental services. Environmental reliance is operationalised as the share of environmental income in total household income reflecting its relative importance (Angelsen et al., 2014). Total income is composed of three income categories: environmental income, agricultural income (from crop and livestock production) and non-farm income (wages, business, remittance, pension, and other income sources). Assets are stocks of capital owned and accessed by the households used to generate the means of living and maintain well-being, and contains five categories of natural, physical, financial, human and social capitals (Ellis, 2000).

3. Methods

3.1. Study area

The transboundary Greater Serengeti-Mara Ecosystem covers an area of approximately 30,000 km^2 on the Tanzania-Kenya border and hosts the world's largest remaining wildlife migration of more than two million large herbivores, primarily wildebeests (Veldhuis et al., 2019). The ecosystem is a complex of protected areas, including the Serengeti National Park, Ngorongoro Conservation Area, Maswa, Grumeti and Ikorongo Game Reserves, and Loliondo Game Controlled Area in Tanzania, and the Maasai Mara National Reserve in Kenya (see Fig. 2). Around the protected areas are pastoral and agro-pastoral communities with a population of more than three million people and numerous livestock, both growing at a high rate (Dublin and Ogutu, 2015; Dybas, 2011; Estes et al., 2012; URT, 2013). Ethnic groups include the Maasai to the north and east, the Sukuma to the south, and the Kuria and other Bantu tribes to the west.

3.2. Data collection

Data was collected in 25 rural villages in the five Tanzanian districts Ngorongoro, Meatu, Bariadi, Serengeti, and Tarime, and in Narok county in Kenya. Site and village selection aimed to capture variations in characteristics such as population density, distance to the boundary of the nearest protected area, ethnic composition, dominant livelihood strategy, precipitation, soil quality, habitat, and infrastructure. To further enable evaluation of the impact of protected area adjacency, villages were as far as possible selected in clusters of three in each district at increasing distance (up to 42 km) from the closest protected area boundary where consumptive activities (e.g. settlement, agriculture, livestock grazing, or environmental product collection) are not allowed (i.e. the National Park and Game Reserves in Tanzania, and the Maasai Mara National Reserve in Kenya). Boundaries of multiple-use zones such as Conservation Areas, Game Controlled Areas and Conservancies were not considered when calculating the distance to nearest protected area boundary.

Approximately forty households were selected in each village based on a stratified random sample selection strategy: 15 poor, 15 intermediate, and 10 rich households. Sampling weights were used in the analysis, defined as the inverse of the probability of being included in the sample at the village level. Replacement of drop-out households from a list of back-up household was applied to minimise attrition (n = 18). Data from at least three quarters were required for inclusion

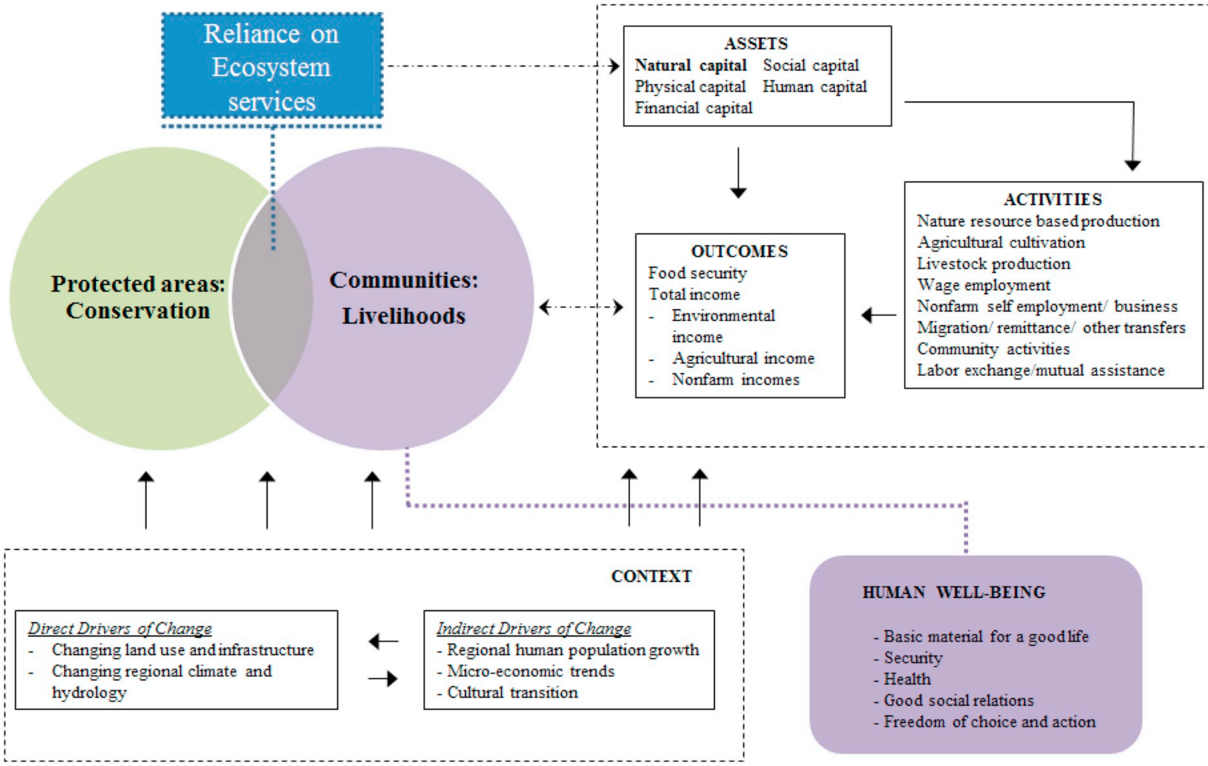

Fig. 1. Theoretical framework integrating the Millennium Ecosystem Assessment and the Sustainable Livelihoods Framework (adapted from Ellis, 2000; MA, 2003; Scoones, 1998; Winters et al., 2001).

of households in the analysis. Hence, no replacement was allowed after the second round of four quarterly surveys. Households with two or more missing quarterly surveys were dropped from the dataset resulting in an attrition rate of 3.2%. The final dataset consisted of 985 households. No systematic pattern of attrition was observed.

Survey instruments were adapted from the PEN prototype questionnaire (PEN, 2007a) and technical guidelines (PEN, 2007b), involving two annual and four quarterly household surveys over the course of a year (May 2016 – April 2017). The quarterly surveys used short recall periods (1–3 months depending on income source – 1 month for environmental income) to improve accuracy and minimise errors arising from long recall periods and seasonal fluctuations in income (Angelsen et al., 2011). The quarterly surveys recorded detailed information about cash and subsistence income in the categories environmental, crop, livestock, business, wage, and other income sources (e.g., remittance or pensions). The first annual survey, implemented at the beginning of data collection, focused on household demographics and assets owned. The second annual survey, implemented at the end of fieldwork, collected information on shocks and changes in asset holdings during the survey year, and included questions about household well-being (see Appendix A) adapted from Yang et al. (2013a). In addition, two village surveys collected data common to all households in the village at the beginning and the end of the fieldwork period. Data was collected through face-to-face questionnaire interviews by trained Swahili speaking enumerators using an Open Data Kit (ODK) tablet interface.

3.3. Data analysis

Three main analyses were undertaken: 1) Calculation of absolute and relative household income for all income sources and analysis of environmental income across well-being quintiles; 2) Construction of well-being sub-indices and an overall Well-Being Index (WBI) using confirmatory factor analysis; and 3) Multivariate regression analysis of models specified to test the four hypotheses (cf. above).

Own reported farm-gate prices were used in calculating the value of environmental, crop, and livestock products wherever possible. Local market price, substitute price, or the opportunity cost of time was used for products not commonly traded locally. Annual household income from each source was calculated by aggregating (and extrapolating – for information obtained using 1 month recall – i.e. enviromnetal income) income data from the four quarterly surveys. Missing household quarterly income ($n = 42$ households missing one quarter) was estimated from average household income in the three sampled quarters multiplied by a factor to capture seasonal variation at the village level following Angelsen et al. (2014). Incomes were converted to Adult Equivalent Units (AEU) following Cavendish (2000) and corrected for Purchasing Power Parity to facilitate comparison across households and between the two countries. District or regional level reliance is calculated as the share of mean income from a particular source in mean total income in that district or region, to avoid distorted values of reliance (share of total income) caused by the negative crop and livestock incomes occurred due to crop failure and/or livestock death during a drought year.

Confirmatory factor analysis (CFA) was used to construct the five sub-indices (“Basic Material for a Good Life”, “Safety”, “Health”, “Social Relations”, and “Freedom of Choice and Action”) and the overall WBI following Yang et al. (2013a). The internal validity and reliability of indicators were assessed using Cronbach's alpha coefficients and item-correlations (Brown, 2006). Two indicators were excluded due to low consistency with other indicators (the local crime incidence in the “Safety” sub-index, and the leisure activities in the “Health” sub-index). The WBI has satisfactory internal validity with a Cronbach's alpha value of 0.89 and item-total correlations ranging from 0.41 to 0.82 within each sub-index (see Appendix A for details). All model fit statistics for the WBI and the individual sub-indices have high goodness-of-fit. The Comparative Fit Index (CFI) is above 0.99, and both the Root Mean Squared Error of Approximation (RMSEA) and the Standardized Root Mean Squared Residual (SRMR) are < 0.08 in all cases. The latent variables and paths of indicators for all five well-being sub-indices have

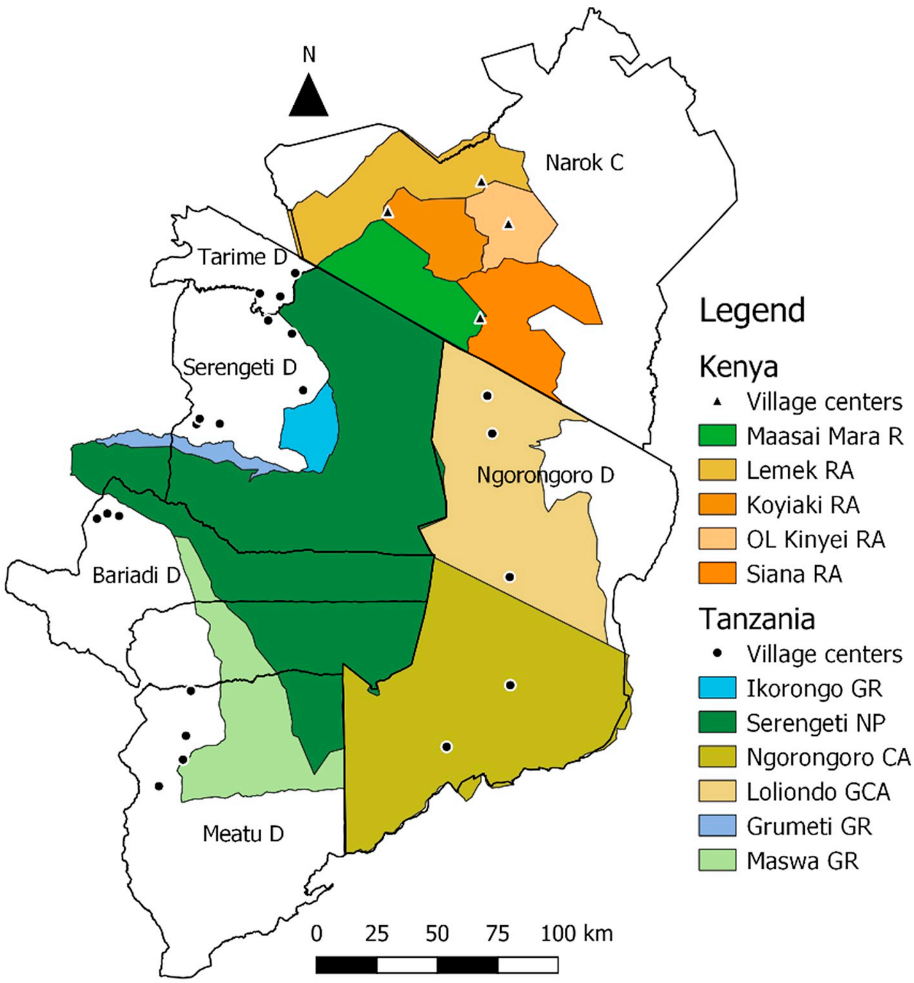

Fig. 2. Map showing the surveyed villages in the Greater Serengeti Mara Ecosystem. Note: C = County; D = District; R = Reserve; RA = Reserved Area (Conservancy); CA = Conservation Area; GR = Game Reserve; NP = National Park; and GCA = Game Controlled Area.

significant coefficients ($p < .01$). The overall model indicates that the five dimensions of human well-being are not independent of each other. The sub-index of "Freedom of Choice and Action" is significantly positively associated with the sub-index of "Social Relations" and "Basic Materials for a Good Life", and the sub-index of "Safety" is significantly positively associated with the Social Relations sub-index. The overall WBI and the sub-indexes were normalised (to a range of 0–100) to enable cross-group comparisons (see Appendix B).

Multivariate regression models were applied to test hypotheses 1–4 and to explore the significance and direction of influence of covariates of environmental reliance, absolute environmental income, and the well-being indices (i.e. the control variables). Control variables were selected based on empirical evidence on the determinants of environmental reliance (e.g. Angelsen et al., 2014; Charlery and Walelign, 2015; Nielsen et al., 2012), rural livelihoods (e.g. Ellis, 2000; Jiao et al., 2017; Scoones, 2015; Walelign et al., 2017), and well-being (e.g. Reyes-García et al., 2016; Yang et al., 2015). Control variables included: household characteristics (tribe, age, and gender of the household head), number of income shocks experienced by the household during the past 12 months (e.g. crop failure, illness, or death of household members), and a country variable. Years of education of the household head, size of the household cropland and the combined value (PPP USD per AEU) of household asset holdings (e.g. motorbikes, mobile phones, equipment) were included as indicators of wealth to test Hypotheses 1 and 2. The size of cropland and value of asset holdings are reflected in the basic material dimension of WBI and were therefore excluded from models for the well-being indices to avoid endogeneity (i.e. circular conclusions in relation to the variables used to construct these indices). Relative environmental income is included in the models predicting WBI and the well-being sub-indices to test Hypothesis 3. In addition, heteroskedasticity-based instrument variables for environmental reliance were applied to address potential endogeneity in the model for the sub-index for "Basic Material for a Good Life" (see Appendix K). Following Lewbel (2012), heteroscedastic based instruments are generated through the interaction between the demeaned (centered) regressors and the error term of the environmental reliance regression model (see Appendix K). Distance from the household to the nearest protected area boundary was included in all models to test Hypothesis 4. Expected signs of explanatory variables and summary statistics are presented in the Table 1 and Appendix B, respectively.

The sample included households nested in 25 villages and five districts and one county, constituting communities of numerous ethnic groups distributed in a matrix of different geographic and cultural contexts. Mixed (or hierarchical) models were therefore used to capture between village and district heterogeneity by including random intercepts (or random coefficients). In addition, random slopes were included at the appropriate level allowing relevant variables to have different effects at different administrative levels (Gelman and Hill, 2006). Comparison of various candidate models was undertaken using likelihood ratio tests (interclass correlation coefficient ICC, the Bayesian and Akaike's Information Criteria, i.e. BIC and AIC) with the most parsimonious models selected (see Table 3). Eq. (1) describes the generic formula of a model with a random intercept (μ_{0j} and μ_{0k} for district and village levels, respectively) and a random slope (μ_1 and μ_2 at district

Table 1
Explanatory variables and expected signs of coefficients in the multivariate regression models predicting environmental reliance, absolute environmental income, the overall well-being index (WBI) and the well-being sub-indexes.

	Environmental income		Well-being sub-indexes					
	Relative (Reliance)	Absolute	Overall WBI	Basic material	Safety	Heath	Social relations	Freedom of choice
Tribe	±	±	±	±	±	±	±	±
Household education (years)	−	−	+	+	+	+	±	+
Female headed household (0/1)	+	−	−	−	−	−	±	−
Age of household head (years)	−	−	+	+	+	−	+	±
Crop land size (Hectares)	−	−						
Total asset value (USD PPP)	−	+						
Shocks in the past 12 months (numbers)	+	+	−	−	−	−	−	−
Country – Kenya (Tanzania as the base group)	−	−	+	+	+	+	+	+
Distance to protected area (km)	−	−	+	+	+	+	±	+
Environmental reliance (%)			−	−	−	−	−	−

and village levels, respectively), where Y_{jki} represents well-being score or environmental reliance of household i in village k and district j, X_{jki} is vector of explanatory variables and β_1 is the associated vector of coefficients, the term e_{jki} represents the error term, and the subscripts i, k, and j are household, village and district respectively.

$$Y_{jki} = \beta_0 + \mu_{0j} + \mu_{0k} + \beta_1 X_{jki} + \mu_1 X_{ji} + \mu_2 X_{ki} + \ldots + e_{jki} \tag{1}$$

We expect that the geographical location affects how age and gender influence environmental income and reliance through variations in environmental and/or habitat quality characteristics between villages irrespective of districts, and through social and cultural differences between tribes residing in different areas (also irrespective of district). Hence, the model predicting environmental reliance was specified with a village level random intercept and random slopes of gender and age of the household head. The model predicting absolute environmental income was specified with village as a random intercept and random slopes of gender and age of the household head and asset value. The models predicting WBI and the well-being sub-indices were specified with random intercepts of both village and district as different policies at the district level affect well-being. These models included a random slope of environmental reliance at the district level, capturing variation in overall habitat types across districts.

Support for the random intercepts and slopes were evaluated using likelihood ratio tests. Dependent variables were mean centred and standardized (by subtracting the mean and dividing by the standard deviation) to normalise the distribution, except environmental reliance which was logit transformed to accommodate the proportional nature of the variable (Baum, 2008). The model predicting logit transformed environmental reliance was implemented using a procedure equivalent to the fractional logit model described in Baum (2008). Illogical values of environmental reliance (i.e. values below 0, originating from rare cases of negative total income due to input costs exceeding gross income, or values above 1, caused by negative total income due to crop failure or livestock death and hence negative crop and/or livestock income while positive environmental income), were adjusted to 1. The alternative approach of replacing such values with village averages tends to underestimate reliance for such households. All models were estimated with heteroscedasticity robust standard errors.

4. Results

First, we estimate total household income and examine differences in income portfolios across geographical and administrative units in the study area. We then test the four hypotheses.

4.1. Environmental income and reliance

Total annual household absolute and relative incomes across geographical locations and administrative units are presented in Table 2 (see Appendix C for pairwise comparison of income sources). In general, the lowest mean total annual household income was observed in the Southern part of the study area, while households in Loliondo to the East in Tanzania and in Narok County in Kenya in the Northern area enjoyed the highest total income. Total annual household environmental income averaged 378 USD PPP/AEU in Tanzania and 281 in Kenya, primarily obtained as subsistence income from firewood, wild foods, water for domestic use, and construction material (the proportion of cash vs subsistence environmental income is presented in Appendix J). Households in Loliondo earn the highest average environmental annual income of 741 USD PPP/AEU, while the lowest environmental income is 167 USD PPP/AEU in the Southern part. The average environmental reliance was 20%, ranging from 39% in the Eastern part in Tanzania to 8% in Narok County in Kenya. Despite high average environmental reliance (30%) in the Western part, the average absolute environmental income is almost half that of the Eastern side.

Livestock is by far the most important income source in the Greater Serengeti-Mara Ecosystem, ranging between on average 29%–60% of total annual household income. Average livestock reliance is 52% on the Kenyan side and 45% in Tanzania. Households in Loliondo and Narok obtained livestock income about five-fold higher than in the Western part, and almost ten-fold greater than in the Southern part of the Greater Serengeti-Mara Ecosystem. Average absolute annual crop income was relatively low, ranging from 22 USD PPP/AEU (in Ngorongoro Conservation Area) to 317 (in Loliondo). Crop income contributed on average 12% of total household income in Tanzania but only 1% in Narok County in Kenya. Average crop income reliance was significantly higher in Meatu district (p-value < 0.05), but no significant differences were observed between other districts. In total, ecosystem derived income (i.e. combined environmental, agricultural and livestock derived income) accounted on average for 75% of total income, varying from 70% to 89% in Ngorongoro Conservation Area and Narok, respectively. The main non-ecosystem dependent income sources are wage income and business, contributing on average 11 and 10% of total income, respectively. Business and wage income were most important for households in the Nngorongoro Conservation Area.

4.2. Income, assets and environmental reliance

Here we focus on the variation of absolute environmental income and reliance across income quintiles testing Hypotheses 1 and 2. In both Tanzania and Kenya, absolute environmental income increases whereas reliance decrease as income increase (Fig. 3 and Appendix D). Environmental reliance for the poorest quintile (20% of the sample with the lowest income) was 81% on average in Tanzania. This extremely high reliance follows from negative crop income as the case study year was characterized by drought. Absolute environmental income was six times higher in the most well-off income quintile compared to the poorest. In Kenya, the two highest income quintiles relied minimally,

Table 2
Total annual household absolute (USD PPP) and relative (%) income per adult equivalent unit by income source across regions and districts in the Greater Serengeti-Mara Ecosystem, 2016–2017. Standard errors in parenthesis.

Regions & Districts	Environmental income (1)		Crop income (2)		Livestock income (3)		Ecosystem derived income (4 = 1 + 2 + 3)		Business income (5)		Wage income (6)		Other income (7)		Non-ecosystem derived income (8 = 5 + 6 + 7)		Total income (4 + 5 + 6 + 7)
	Abs[a]	Rel[b]	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel	Abs
Southern	167 (8)	23	135 (22)	19	263 (29)	36	565 (39)	78	43 (10)	6	91 (30)	13	24 (6)	3	158 (38)	22	723 (52)
Meatu district	150 (9)	20	184 (35)	25	247 (34)	33	581 (53)	78	42 (13)	6	94 (40)	13	32 (10)	4	168 (50)	22	749 (68)
Bariadi district	190 (15)	28	68 (22)	10	285 (50)	41	543 (59)	79	44 (16)	6	88 (45)	13	14 (2)	2	146 (58)	21	689 (79)
Western	391 (21)	32	174 (18)	14	441 (55)	36	1006 (69)	82	72 (11)	6	124 (37)	10	23 (6)	2	220 (39)	18	1226 (78)
Serengeti district	383 (22)	33	183 (24)	16	395 (66)	34	961 (83)	82	72 (14)	6	107 (47)	9	29 (10)	2	208 (51)	18	1169 (97)
Tarime district	407 (45)	30	157 (27)	12	535 (100)	40	1098 (122)	82	73 (16)	5	157 (56)	12	13 (3)	1	243 (60)	18	1341 (133)
Eastern (Ngorongoro district)	659 (41)	23	203 (45)	7	1543 (194)	55	2405 (217)	85	292 (81)	10	113 (28)	4	14 (3)	0	419 (86)	15	2825 (226)
-Ngorongoro Conservation Area	531 (57)	39	22 (15)	2	399 (80)	29	952 (121)	70	188 (66)	14	205 (63)	15	18 (8)	1	411 (100)	30	1363 (159)
Loliondo	741 (54)	20	317 (70)	8	2267 (294)	60	3324 (318)	85	358 (125)	10	55 (20)	4	12 (2)	0	425 (125)	15	3749 (328)
Northern (Narok county)	281 (20)	8	31 (11)	1	1924 (467)	52	2236 (467)	89	521 (75)	10	644 (143)	1	311 (41)	0	1477 (190)	11	3713 (525)
All Sample	362 (13)	20	145 (13)	8	845 (90)	47	1353 (94)	75	180 (21)	10	197 (29)	11	69 (8)	4	445 (42)	25	1799 (107)

[a] Abs = absolute income.
[b] Rel = relative income (% of total income). These are calculated as the share of mean income from a particular source in mean total income in that district or region. Thus no standard errors are reported.

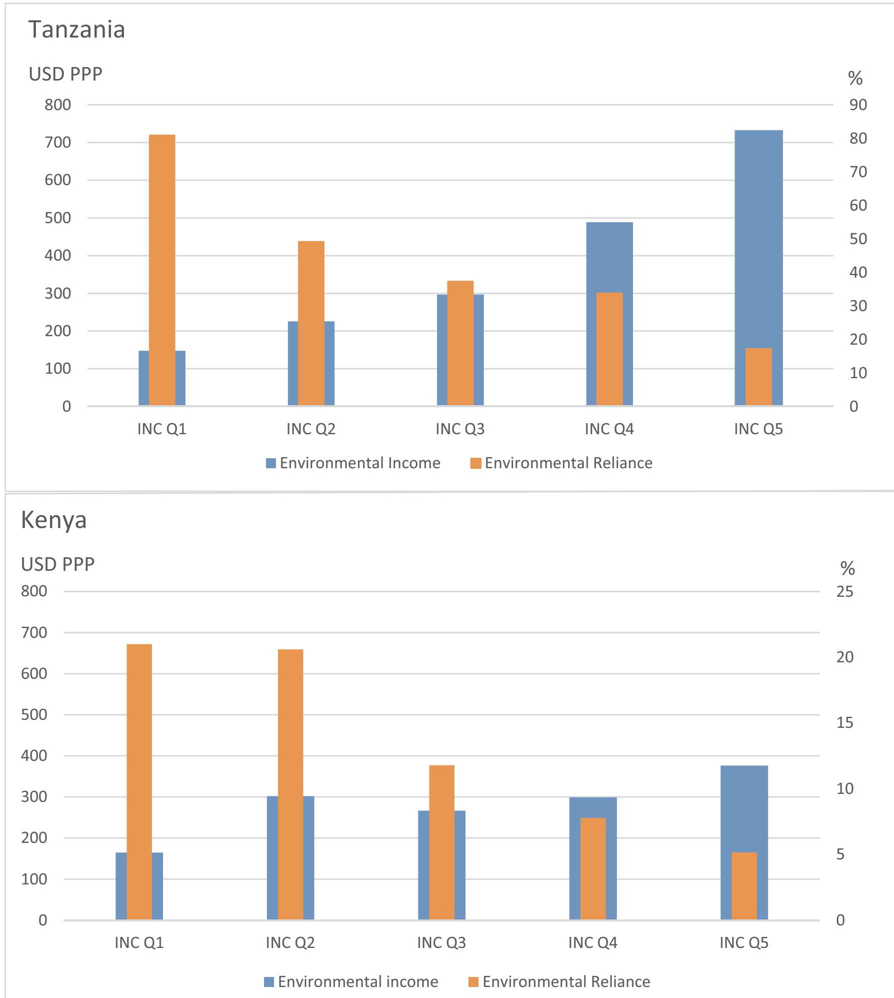

Fig. 3. Annual household environmental income and reliance across income quintiles in the Greater Serengeti-Mara Ecosystem, 2016–2017.

i.e. < 10%, on environmental income, while reliance in the two poorest income quintiles was around 20% on average. Absolute environmental income was similar in the four highest income quintiles, at a level double that of the lowest quintile. These trends are also supported by the results in Appendix E presenting linear fitted trend lines for absolute environmental income and reliance plotted against total household income in Tanzania and Kenya. The slope coefficients of the fitted lines are significant in all models although model explanatory power (R-squared) is low. A more detailed account of annual total household income composition across income quintiles is presented in Appendix D and pairwise comparisons between income quintiles in Appendix H.

The results of the multivariate regression models are presented in Table 3. Age and years of education of the household head were negatively associated with both absolute environmental income and reliance (at the 0.1 level). Area of cropland owned was negatively related to environmental reliance only. The value of asset holdings, an indicator of more permanent as opposed to more transitory wealth reflected by income, is positively associated with absolute environmental income and negatively associated with reliance. Evaluating the effect of the control variables, both absolute environmental income (on the 0.1 level) and reliance decrease as the number of shocks experienced during the past 12 months increase. In the model predicting reliance, the positive correlations of the random slope of age and gender of the household head with the village level random intercept reveal that the effect of age and gender is larger in villages with higher average environmental reliance. In the absolute environmental income model, the negative correlations of the village level random slope of asset value, age and gender of the household head with the village level intercept reveal that the observed effects of these variables are larger in villages with lower average environmental income.

4.3. Environmental income and reliance across well-being quintiles

Here we focus on the variation of annual household environmental income and reliance across well-being indicie quintiles (Fig. 4). Absolute environmental income does not differ significantly between well-being quintiles in Tanzania or Kenya (see Appendix I for pairwise comparisons between well-being quintiles). Environmental reliance exhibits a declining pattern with increasing well-being quintiles in both Tanzania and Kenya, except households in the fourth quintile. The relationships are also examined using scatterplots and fitted lines in Appendix G, confirming the negative association between well-being and environmental reliance. A more detailed account of annual household income composition across well-being quintiles is presented in Appendix F.

The results of the multivariate regression models are presented in Table 3. Environmental reliance is negatively associated with WBI and the sub-indices for “Basic Material for a Good Life” and “Health”. Results from the Two-Stage Least Squares Instrumental Variable (2SLS IV) regression model (see Appendix K) confirm the negative relationship between environmental reliance and the sub-index of “Basic Material for a Good Life”. The positive correlation of the district level random

Table 3
Multivariate regression models predicting (i) environmental income and reliance, and (ii) overall well-being index (WBI) and well-being sub-indices in the Greater Serengeti-Mara Ecosystem, 2016–2017.

	Environmental income		Well-being Index and sub-indices					
	Reliance	Absolute	Overall WBI	Basic materials	Safety	Health	Social relations	Freedom of choice
Environmental reliance			−0.467** (0.226)	−0.715*** (0.263)	−0.177 (0.131)	−0.344** (0.171)	−0.296 (0.336)	−0.602 (0.424)
Household education (years)	−0.047* (0.026)	−0.052* (0.030)	0.044*** (0.014)	0.070*** (0.012)	0.031** (0.013)	0.033* (0.020)	−0.007 (0.014)	0.047*** (0.017)
Female headed household (0/1)	0.175 (0.165)	−0.060 (0.094)	−0.323 (0.199)	−0.312* (0.183)	0.038 (0.101)	−0.312* (0.186)	0.037 (0.027)	−0.287 (0.188)
Age of household head (years)	−0.009*** (0.004)	−0.009*** (0.004)	0.001 (0.001)	−0.004 (0.002)	0.008* (0.004)	−0.0002 (0.001)	0.003 (0.001)	0.002* (0.001)
Crop land size (hectares)	−0.072*** (0.012)	0.010 (0.012)						
(log)Total Asset value (USD PPP/AEU)	−0.164*** (0.058)	0.090** (0.038)						
Shocks experienced (number past 12 months)	−0.149** (0.068)	−0.063* (0.036)	−0.178*** (0.039)	−0.060* (0.031)	−0.127*** (0.012)	−0.187*** (0.044)	−0.009 (0.018)	−0.052** (0.022)
Distance to protected area (km)	0.031 (0.049)	−0.043*** (0.012)	0.049*** (0.015)	0.067** (0.031)	−0.005 (0.030)	0.047*** (0.016)	−0.030** (0.012)	0.033*** (0.009)
Tribe								
Maasai	−0.093 (0.616)	−0.359 (0.570)	−0.117 (0.086)	−0.331*** (0.094)	0.308*** (0.054)	−0.073 (0.122)	−0.040 (0.065)	−0.349** (0.147)
Sukuma	−0.063 (0.352)	−0.299 (0.204)	−0.086 (0.126)	−0.286 (0.214)	0.310*** (0.109)	−0.053 (0.137)	0.099*** (0.024)	−0.318 (0.259)
Kuria	1.243 (0.869)	0.480 (0.400)	−0.091 (0.150)	0.03301 (0.229)	0.260 (0.371)	−0.126 (0.174)	0.572* (0.294)	−0.235 (0.284)
Country								
Kenya	−2.296*** (0.849)	0.328 (0.501)	−1.209*** (0.276)	−0.820*** (0.216)	−0.633 (0.385)	−1.119*** (0.308)	−1.358*** (0.225)	−1.207*** (0.124)
Constant	−0.337 (0.326)	0.054 (0.307)	0.214 (0.212)	0.249* (0.133)	−0.125 (0.165)	0.203 (0.234)	−0.012 (0.246)	0.328 (0.203)
Village constant (sd)	0.778 (0.085)	0.652 (0.108)	0.449 (0.138)	0.615 (0.153)	0.350 (0.050)	0.444 (0.141)	0.407 (0.065)	0.332 (0.077)
District constant (sd)			0.189 (0.151)	0.056 (0.065)	0.064 (0.065)	0.150 (0.160)	0.477 (0.864)	0.189 (0.102)
Random slope (sd)								
Female headed household (Village level)	0.813 (0.121)	0.530 (0.110)						
Age of household head (Village level)	0.017 (0.002)	0.013 (0.003)						
(log)Asset value (Village level)		0.119 (0.018)						
Environmental reliance (District level)			0.491 (0.085)	0.541 (0.107)	0.260 (0.043)	0.375 (0.092)	0.772 (0.291)	0.952 (0.232)
Correlation of random slope and model constant								
Female headed household	0.173 (0.230)	−0.280 (0.366)						
Age of household head	0.276 (0.206)	−0.259 (0.285)						
(log)Asset value		−0.044 (0.256)						
Environmental reliance			0.103 (0.533)	1.000 (0.061)	1.000 (0.0007)	0.136 (0.722)	−0.847 (0.599)	−0.388 (0.369)
Model statistics								
Log-likelihood	−328,811	−225,118	−222,426	−231,946	−220,871	−226,086	−230,414	−232,527
AIC	657,660	450,282	444,884	463,924	441,774	452,204	460,860	465,086
BIC	657,753	450,395	444,962	464,002	441,853	452,282	460,939	465,164
ICC (Village)	0.33787	0.487	0.228	0.197	0.078	0.144	0.458	0.501
ICC (District)			0.166	0.253	0.133	0.175	0.092	0.058
N (Households)	985	985	985	985	985	985	985	985
N (Villages)	25	25	25	25	25	25	25	25
N (Districts)			6	6	6	6	6	6

Note: standard errors in parentheses.
* Indicates level of significance at the 10% level.
** Indicates level of significance at the 5% level.
*** Indicates level of significance at the 1% level.

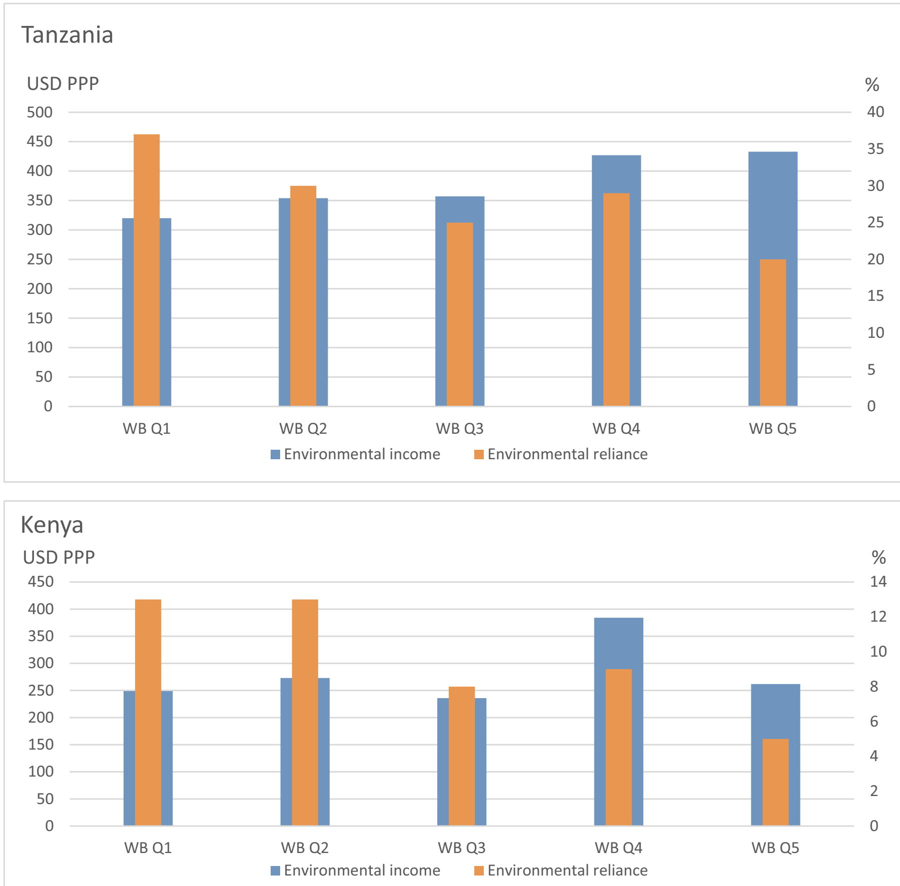

Fig. 4. Annual household environmental income and reliance across well-being quintiles in the Greater Serengeti-Mara Ecosystem, 2016–2017.

slope of reliance and the district level random intercept implies that the negative effect on well-being is stronger in districts with higher average well-being. Households with more educated heads have significantly higher WBI. Education is also significant for all sub-indices except "Social Relations" (at the 0.1 level for "Health"). Female-headed households have significantly lower well-being sub-indices on "Basic Material for a Good Life" and "Health" (on the 0.1 level). The sub-indices on "Safety" and "Freedom of Choice and Action" are significantly positively associated with household head age (on the 0.1 level). Unsurprisingly, a higher number of shocks experienced was negatively associated with WBI and all sub-indices except "Social Relations" that represents a particularly important capital when coping with shocks.

4.4. The effect of distance to the protected area boundary

The results of the multivariate regression models (Table 3) show that distance to the boundary of the core protected area is negatively associated with environmental income, implying that households living closer to protected areas have higher environmental income. There was no significant relationship with distance in the regression model predicting reliance. However, the plot in Fig. 5 show a negative relationship between distance to protected area boundary and environmental reliance. The relationship between WBI and the sub-indices and distance was positive with the exception of the "Safety and Social Relations" sub-indices. This indicates that households further from protected areas generally experience higher well-being ceteris paribus (i.e. all else equal). Distance had a negative effect on the "Social Relations" sub-index suggesting that households living closer to protected area boundaries tend to form more closely-knit communities. Maasai households have lower well-being on the "Basic Material for a Good Life" and "Freedom of Choice and Action" sub-indices but higher on the "Safety" sub-index compared to other tribes. Sukuma households tend to have higher well-being on the "Safety" and "Social Relations" sub-indices and the Kuria have higher "Social Relations" sub-index compared with other tribes (on the 0.1 level). Holding all other variables equal, households living in Narok County in Kenya tend to have lower well-being on most indices.

5. Discussion

5.1. Importance of environmental income

Environmental income is important to households in villages in and around the Greater Serengeti-Mara Ecosystem. Environmental income accounts for 8–39% of total household income, with an average of 20%. Adding crop (8%) and livestock (47%) incomes, the average ecosystem derived income accumulates to 75% in the study area, and is hence higher than the equivalent 69% reliance recorded in the global PEN survey (Angelsen et al., 2014). Such high ecosystem reliance implies that the study communities are highly vulnerable to declining ecosystem services provisioning. Hence, to fully understand household income portfolios and rural realities in the Greater Serengeti-Mara Ecosystem, environmental income cannot be disregarded and needs to be integrated into the design of processes modifying environmental resource access regulations. We found considerable variation in environmental income patterns. Communities in the Western part of the study area and the Ngorongoro Conservation Area rely most on environmental income. This may be attributed to restrictions on livelihood activities, in particularly crop production in the Ngorongoro Conservation Area (Charnley, 2005; Masao et al., 2015), in

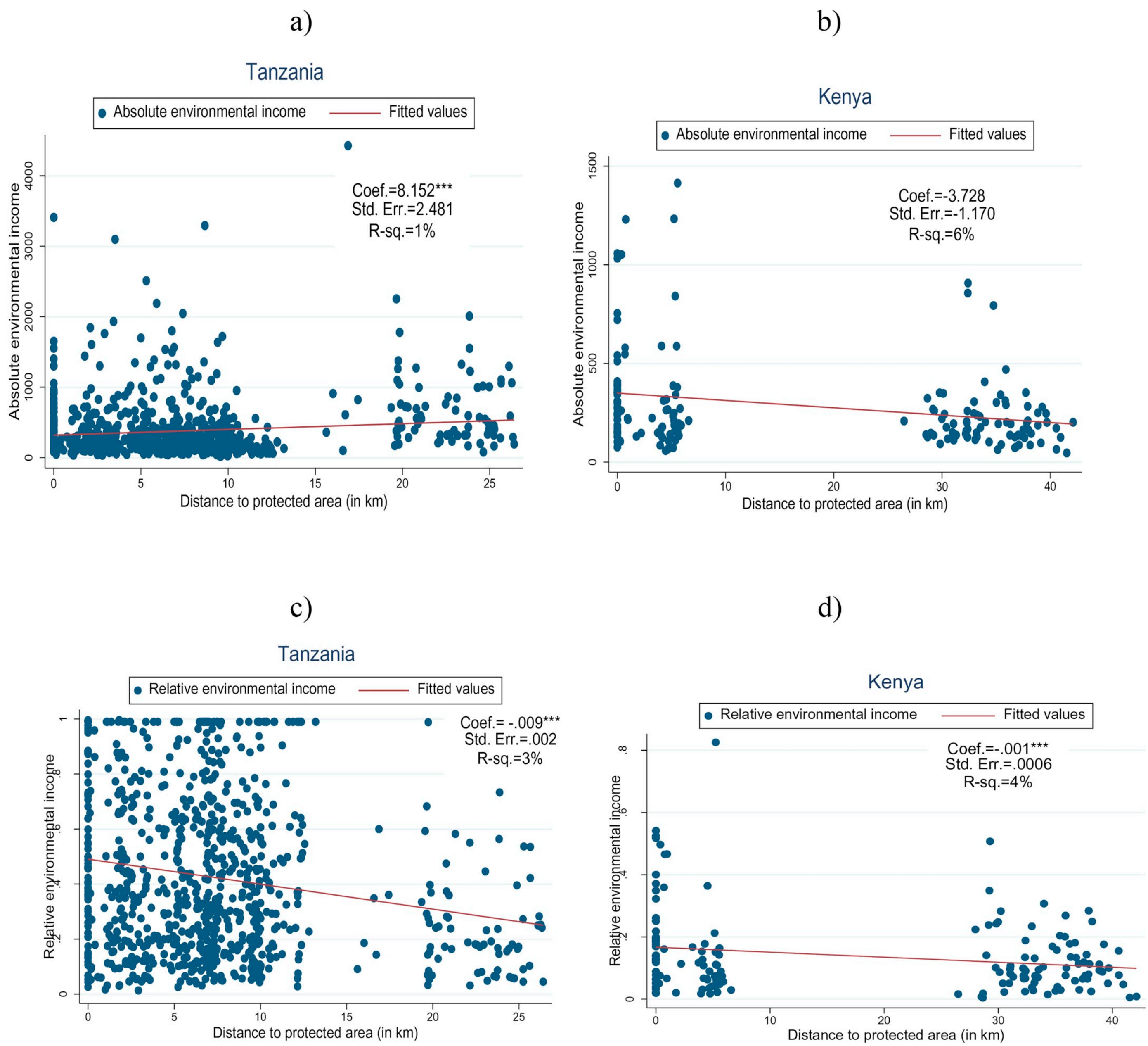

Fig. 5. The relationships between absolute environmental income and environmental reliance and distance to the core protected area boundary in Tanzania and Kenya.

combination with poor infrastructure restricting market access. It should also be noted that although environmental income appears to be high in the study area, the estimates should be considered conservative since illegal extraction activities may be underreported (Nuno and John, 2015). For instance, only around 2% (1.7 and 2.7% including and excluding Maasai) of our sampled households reported bushmeat income while estimates from Western Serengeti report such income from 3 to 73% of households depending on survey methods (Holmern et al., 2002; Johannesen, 2005; Knapp, 2007; Knapp et al., 2010; Mfunda and Roslash, 2010). A recent study using methods designed specifically for assessing the prevalence of sensitive activities reported the involvement of 18% of households in illegal bushmeat hunting (e.g. Nuno et al., 2013). However, that survey was conducted in areas where hunting is known to be common.

5.2. Patterns of environmental income

As postulated by Hypothesis 1, we observed a negative association between income and environmental reliance confirming findings in a range of other locations in Africa (Angelsen et al., 2014; Babulo et al., 2009; Dokken and Angelsen, 2015; Mamo et al., 2007; Vedeld et al., 2007). As predicted by Hypothesis 2, we also found that higher income quintiles earn more absolute environmental income, again consistent with most studies of links between poverty and the environment (Angelsen et al., 2014; Babulo et al., 2009; Vedeld et al., 2007). However, these patterns were less pronounced in the Kenyan part of the study area, where environmental reliance is high only among households in the lowest income quintiles, and where absolute environmental income did not vary much above the lowest income quintile. This indicates that wealthier households in Tanzania extract more environmental products than in Kenya where such households may prefer and have access to substitute products (e.g. gas for cooking or bricks for housing).

The multivariate regression analyses also support Hypothesis 1. There was a negative association between reliance and education, cropland, and total asset value owned. However, Hypothesis 2 was only supported by the positive association between absolute environmental income and total asset value. Contrary to Hypothesis 2, the association with total income was negative which may be explained by wealthier household heads engaging in more profitable income generating activities than environmental product harvesting. We also found a negative association between shocks experienced and absolute environmental income and reliance suggesting that households do not rely on environmental income as a safety net to cope with shocks. This observation is consistent with findings from the global PEN study (Wunder et al., 2014) as well as more recent work on environmental reliance dynamics (Walelign and Jiao, 2017) although other patterns have also been observed (Debela et al., 2012; Eriksen et al., 2005; Völker and Waibel, 2010). In line with previous studies (e.g., Angelsen et al., 2014; Babulo et al., 2008; Mamo et al., 2007), we found that households with younger and less-educated household heads have higher environmental income and reliance reflecting fewer other livelihood opportunities.

Overall, the results support Hypotheses 1 and 2 indicating that the poorest households are not responsible for the highest direct extractive pressure on the GSME. Better-off households, in terms of wellbeing scores and income without controlling for other aspects, extract a larger amount of environmental products. The poorer households, however, are more vulnerable to reduced ecosystem service provision due to their higher environmental reliance.

5.3. Well-being is inversely related to environmental reliance

As expected by Hypothesis 3, well-being increased as environmental reliance declined. There was no significant relationship between absolute environmental income and well-being. Hence, low well-being households rely more on environmental income, and higher absolute environmental income does not lead to improved well-being. The finding highlights the importance of using multi-dimensional welfare measures as different patterns are observed for both environmental income and reliance when compared as a fundtion of well-being groups and income groups. Previous studies have also found varied patterns of environmental reliance across welfare grouping when measured using income, asset and a combination of the two (Charlery and Walelign, 2015; Dokken and Angelsen, 2015; Nielsen et al., 2012; Walelign et al., 2017). Interestingly, Kenyan households had lower well-being despite having higher incomes (p-value < 0.01) than Tanzanian households. This suggests that higher income and more assets do not translate directly into higher well-being emphasising the multidimensional nature of well-being.

The multivariate regression analyses generally support Hypothesis 3. There was a negative association between environmental reliance and WBI. Reliance was also negatively associated with the sub-indices of “Basic Material for a Good Life” and “Health”. Households with higher environmental reliance may self-evaluate their well-being lower for two reasons: (i) environmental reliance means increased vulnerability to environmental conditions (e.g. rainfall) and access restriction enforcement (e.g. changing policies and conservation initiatives), and (ii) environmental product collection may be considered an arduous and low prestige activity. The negative relation between well-being and reliance were more pronounced in districts with lower average well-being scores, implying that households with higher environmental reliance living in the low well-being communities are likely to be additionally marginalised. Hence, overall our results support Hypothesis 3. The positive association between education and WBI and most sub-indices underscores the benefit of investing in building human capital in rural communities (Angelsen et al., 2014; Walelign and Jiao, 2017). The number of shocks experienced diminished WBI and all sub-indices except “Social Relations”. This reflects the value of networks and social capital in rural communities for coping with shocks and the importance of the resulting resilience for well-being (Eriksen et al., 2005; Møller et al., 2018; Shiferaw et al., 2014).

5.4. Distance to a protected area boundary is negatively associated with absolute environmental income and reliance but positively associated with well-being

Living adjacent to a protected area is often assumed beneficial as households can extract environmental products and benefit from outreach and integrated conservation and development projects, which has been associated with immigration and high population growth at the boundaries (Chao et al., 2018; Naidoo et al., 2019; Wittemyer et al., 2008). Our results show that households residing closer to the protected area boundaries as expected have higher environmental income. However, they also have lower well-being, and we thus find support for Hypothesis 4. Although households living closer to protected areas benefit from access to natural resources, they are disadvantaged in terms of WBI, “Basic Materials for a Good Life”, “Health”, and “Freedom of Choice”. The lower well-being may be explained by remoteness and the consequent lack of physical infrastructure including limited access to health services and markets, fewer livelihood options, and restrictions imposed by authorities in consideration of conservation objectives. In addition, communities close to protected areas experience higher levels of wildlife crop raiding and livestock depredation. These challenges may, in turn, foster stronger “Social Relations” in communities adjacent to protected areas (Estes et al., 2015; Oglethorpe et al., 2007).

The study year was characterized by a drought that affected household income portfolios compared to a “normal” year. Crop production was seriously reduced, particularly for Sukuma and Kuria agropastoralists living in the southern and western parts of the study area (Sewando et al., 2016). Obtaining valid and accurate information on the economic contribution of bushmeat is complicated by the illegal nature of the practice and respondents' fear of sanctions (Conteh et al., 2015; Nuno and John, 2015). Hence, the presented estimates of environmental income and reliance are probably conservative.

6. Conclusion

Nature provides a substantial economic contribution to households residing in and around the Greater Serengeti-Mara Ecosystem. Poorer households are most reliant on income generated by harvesting environmental products while better-off households harvest larger quantities. While environmental income is essential in households' income portfolios, high environmental reliance is also associated with lower well-being. Hence, according to local own-reported perceptions, a higher quality of life is connected with lower reliance on harvesting environmental products. The reasons for this remain to be better understood but could be driven by restrictions on household activities or a desire to shift out of such arduous activities. Nevertheless, the findings provide inputs for the design of interventions aimed at solving conflicts between enhancing local livelihoods and conservation objectives in the Greater Serengeti-Mara Ecosystem. Such initiatives should acknowledge the high current household reliance on environmental income and then proceed to build on households' association of environmental reliance with lower well-being. This is a positive starting point for engaging households in activities outside environment product harvesting. Potential policy interventions derived from the key findings include enhancing access to education and providing technical assistance and low-interest loans or credit for alternative non-environmental based income generation activities and promoting and strengthening capacity building for sustainable protected area management.

Acknowledgements

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Appendices

Appendix A
Descriptions of indicators and statistics for constructing well-being indices

Indicator	Indicator/indices description	$r_{i\text{-}t}$[a]	Coefficients (Std. Err)[b]
Sub-index 1	Q1. Basic Materials for a Good Life		0.506*** (0.037)
Overall satisfaction with access to basic goods and services	Q1.0: Overall, you are satisfied with the basic goods and services available to your household (e.g., food, clothes, living conditions, transportation) for your daily life	0.80	0.966*** (0.045)
Accessibility and affordability of basic goods and services	Q1.1: It is convenient and affordable for your household to access/purchase necessities (basic goods and material) for daily life	0.82	1.031*** (0.044)
Affordability to necessary food	Q1.2: Your household can afford enough food to stay healthy	0.76	1.003*** (0.044)
Affordability to basic facilities and services	Q1.3: Your household can afford to access basic facilities (e.g., health centre, electricity) and services (e.g., transportation, education)	0.75	0.957*** (0.043)
Satisfaction with housing condition	Q1.4: You are satisfied with your housing condition (including size and quality)	0.71	0.879*** (0.048)
Sub-index 2	Q2:Security		0.372*** (0.035)
Overall satisfaction with security	Q2.0: Overall, you are satisfied with the security of your household (e.g., life and property/assets)	0.76	0.991*** (0.027)
Life safety	Q2.1: Your household members' safety in daily life is secure	0.77	0.865*** (0.024)
Property safety	Q2.2: Your household's property safety in daily life is secure	0.76	0.932*** (0.026)
Local crime incidence	Q2.3: The local crime incidence (e.g., theft, robbery, murder, other violent incidents) is low	–	–
Access to government protection	Q2.4: The police and judicial system is always ready to help	0.65	0.239*** (0.037)
Reliability of government protection	Q2.5: The police and judicial system can be trusted	0.65	0.260*** (0.038)
Security for resource access	Q2.6: It is health wise safe (no contaminations or quality concerns) to access basic goods and services such as food, water, and medicine	0.56	0.401*** (0.042)
Sub-index 3	Q3: Health		0.734*** (0.043)
Overall satisfaction with health status	Q3.0: Overall, you are satisfied with your household's health status	0.76	0.754*** (0.048)
Rest	Q3.1: How often do you feel you do not get enough rest or sleep?	0.58	0.380*** (0.041)
Energy for daily life	Q3.2: How often your household members are not healthy or do not have enough energy for everyday life?	0.71	0.533*** (0.034)
Emotion	Q3.3: How often do you have negative feelings such as unhappy, sad, or worrying?	0.65	0.486*** (0.034)
Physical health	Q3.4: You are satisfied with your household's physical health (including illness and injury)	0.79	0.791*** (0.044)
Mental health	Q3.5: You are satisfied with your household's sense of happiness and healthy mind-set	0.68	0.705*** (0.038)
Leisure activities	Q3.6: How often do your household members have the opportunity for leisure activities?	–	–
Sub-index 4	Q4: Good Social Relations		0.210*** (0.033)
Overall satisfaction with social relationship	Q4.0: Overall, you are satisfied with your household's social relationships with others	0.78	0.495*** (0.022)
Close neighborhood	Q4.1: This is a close-knit neighborhood	0.77	0.501*** (0.025)

(*continued on next page*)

Appendix A (*continued*)

Indicator	Indicator/indices description	$r_{i\text{-}t}$ [a]	Coefficients (Std. Err) [b]
Trust in the community	Q4.2: Most people in this village (refer to the village name) are basically honest and can be trusted.	0.69	0.621*** (0.034)
Opportunities of neighborhood interactions	Q4.3: There are many opportunities to meet neighbors and work on solving community problems	0.80	0.660*** (0.026)
Participation in community activites	Q4.4: Your household members are actively involved/participate in social activities in your community groups or village	0.71	0.551*** (0.024)
Help and mutual support within community	Q4.5: There are always some people ready to help if someone in your village/neighborhood had something unfortunate happen to them, such as a family member's sudden death	0.64	0.362*** (0.020)
Sub-index 5	Q5: Freedom of Choice and Action		0.527*** (0.037)
Overall satisfaction with freedom of choice and action	Q5.0: Overall, you are satisfied with your freedom of choice and actions	0.56	0.262*** (0.035)
Freedom from discrimination	Q5.1. Your household members are always treated equally without regard to gender, tribe, race, language, religion, political beliefs, socioeconomic status and more within your community	0.41	0.224*** (0.040)
Affordability to quality and nutritious food	Q5.2: Your household has affordable access to quality and nutritious food for a satisfied life	0.72	0.898*** (0.048)
Affordability to healthcare	Q5.3: You have access to affordable healthcare as you wish	0.77	1.021*** (0.049)
Affordability to education	Q5.4: You have access to affordable education as you wish	0.73	0.943*** (0.049)
Affordability to quality housing	Q5.5: You have access to affordable quality housing as you wish	0.78	1.051*** (0.050)
Free choice of employment	Q5.6: How difficult is finding a satisfactory job or undertake a livelihood activity?	0.50	0.371*** (0.029)
Freedom of choices and actions to help others	Q5.7. How often do you feel that you want to help others but you cannot, because of limited socioeconomic or physical conditions?	0.45	0.327*** (0.036)

***$p < .001$, **$p < .005$. Two indicators were excluded due to low consistency with other indicators (i.e. Q2.3 and Q3.6). Paths between observed indicators and sub-indices are not shown here.

Options for all indicator contents are designed in the five-category Likert scale. All the responses are coded in the order from the lowest score of 1 to the highest score of 5. A higher score represents a higher level of well-being.

[a] $r_{i\text{-}t}$: item-total correlations.

[b] Coefficients (Std. Err): coefficients are derived from confirmatory factor analysis, standard errors are presented in parentheses.

Appendix B

Descriptive statistics for variables used in the regression models

Variables	Mean	Standard deviation	Min	Max
Dependent variables				
Environmental reliance (relative environmental income %)	0.38[a]	0.29	0	1
Environmental income (adult equivalent USD PPP)	362.31	400.95	20.21	4427.52
Overall Well-being index score (0 − 100)	64.55	17.76	0	100
Basic material for a good life sub-index socre (0–100)	53.77	27.21	0	100
Safety sub-index score (0–100)	83.21	23.49	0	100
Health sub-index score (0–100)	65.87	19.12	0	100
Social Relations sub-index score (0–100)	87.32	14.76	0	100
Freedom of Choice and Action sub-index score (0–100)	48.10	23.30	0	100
Independent variables				
Age of household head (years)	47.38	14.00	19	92
Household education (years)	4.98	4.37	0	30
Female headed household (%)	0.18	0.39	0	1
Crop land size (Hectares)	2.50	5.90	0	101
Total asset value (USD PPP)	614.42	4033.49	0	94,501
Shocks experienced in the past 12 months (numbers)	1.63	1.23	0	11
Distance to protected area (km)	9.09	9.42	0	42.11

(*continued on next page*)

Appendix B (*continued*)

Variables	Mean	Standard deviation	Min	Max
Tribe				
Maasai (%)	0.33	0.47	0	1
Sukuma (%)	0.31	0.46	0	1
Kuria (%)	0.20	0.40	0	1

[a] The mean of environmental reliance at household level here is calculated as the means of individual household income shares (and not the share of mean environmental income in mean total income at district or region levels).

Appendix C

Pairwise comparison of annual total household income (USD PPP per adult equivalent unit) across regions and districts in the Greater Serengeti-Mara Ecosystem using ANOVA with Bonferroni test

Regions & districts	Environmental income	Crop income	Livestock income	Ecosystem derived income	Business income	Wage income	Other income	Non-ecosystem income	Total income
Southern vs. Western	***	NS	NS	NS	NS	NS	NS	NS	NS
Southern vs. Eastern-Ngorongoro Conservation Area	***	NS	NS	NS	NS	NS	NS	NS	NS
Southern vs. Eastern-Loi	***	***	***	***	***	NS	NS	NS	***
Southern vs. Northern	NS	NS	***	***	***	***	***	***	***
Western vs. Eastern-Ngorongoro Conservation Area	***	**	NS	NS	NS	NS	NS	NS	NS
Western vs. Eastern-Loi	***	***	***	***	***	NS	NS	NS	***
Western vs. Northern	***	***	***	***	***	***	***	***	***
Eastern-Ngorongoro Conservation Area vs. Northern	***	NS	***	***	NS	NS	NS	NS	***
Eastern-Ngorongoro Conservation Area vs. Loiondo	***	***	***	**	***	***	***	***	***
Eastern-Loi vs. Northern	***	***	NS	**	NS	***	***	***	NS
Meatu vs. Bariadi	NS	NS	NS	NS	NS	NS	NS	NS	NS
Serengeti vs. Tarime	NS	NS	NS	NS	NS	NS	NS	NS	NS
Nororongoro vs. Narok	***	***	NS	NS	**	**	***	***	NS
Ngorongoro Conservation Area vs. Loiondo	***	***	***	***	NS	NS	NS	NS	***

*, ** and *** signify statistical significance at 0.1, 0.05 and 0.01 levels, respectively. NS = not significant.

Appendix D

Annual total household income in absolute (USD PPP) and relative (%) per adult equivalent unit across income quintile groups in the Greater Serengeti-Mara Ecosystem

Income source	INC Q1		INC Q2		INC Q3		INC Q4		INC Q5	
	Abs[a]	Rel[b]	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel
Tanzania (N = 825)										
Environmental income	148 (7)	81	226 (9)	49	297 (14)	37	489 (30)	34	731 (54)	17
Crop income	−27 (12)	−15	87 (9)	19	143 (14)	18	173 (21)	12	462 (63)	11
Livestock income	37 (6)	20	85 (10)	18	263 (18)	33	568 (37)	39	2230 (230)	52
Business income	9 (3)	5	27 (6)	6	38 (7)	5	108 (22)	7	384 (93)	9
Wage income	7 (2)	4	22 (5)	5	38 (9)	5	84 (20)	6	401 (93)	9
Other income	9 (1)	5	12 (2)	3	18 (4)	2	25 (9)	2	44 (14)	1
Total income	183 (9)	100	460 (7)	100	796 (9)	100	1447 (22)	100	4252 (239)	100
Kenya (N = 159)										
Environmental income	165 (14)	21	302 (43)	21	267 (43)	12	299 (34)	8	376 (66)	5
Crop income	19 (12)	2	−3 (5)	0	78 (43)	3	30 (22)	1	32 (27)	0

(*continued on next page*)

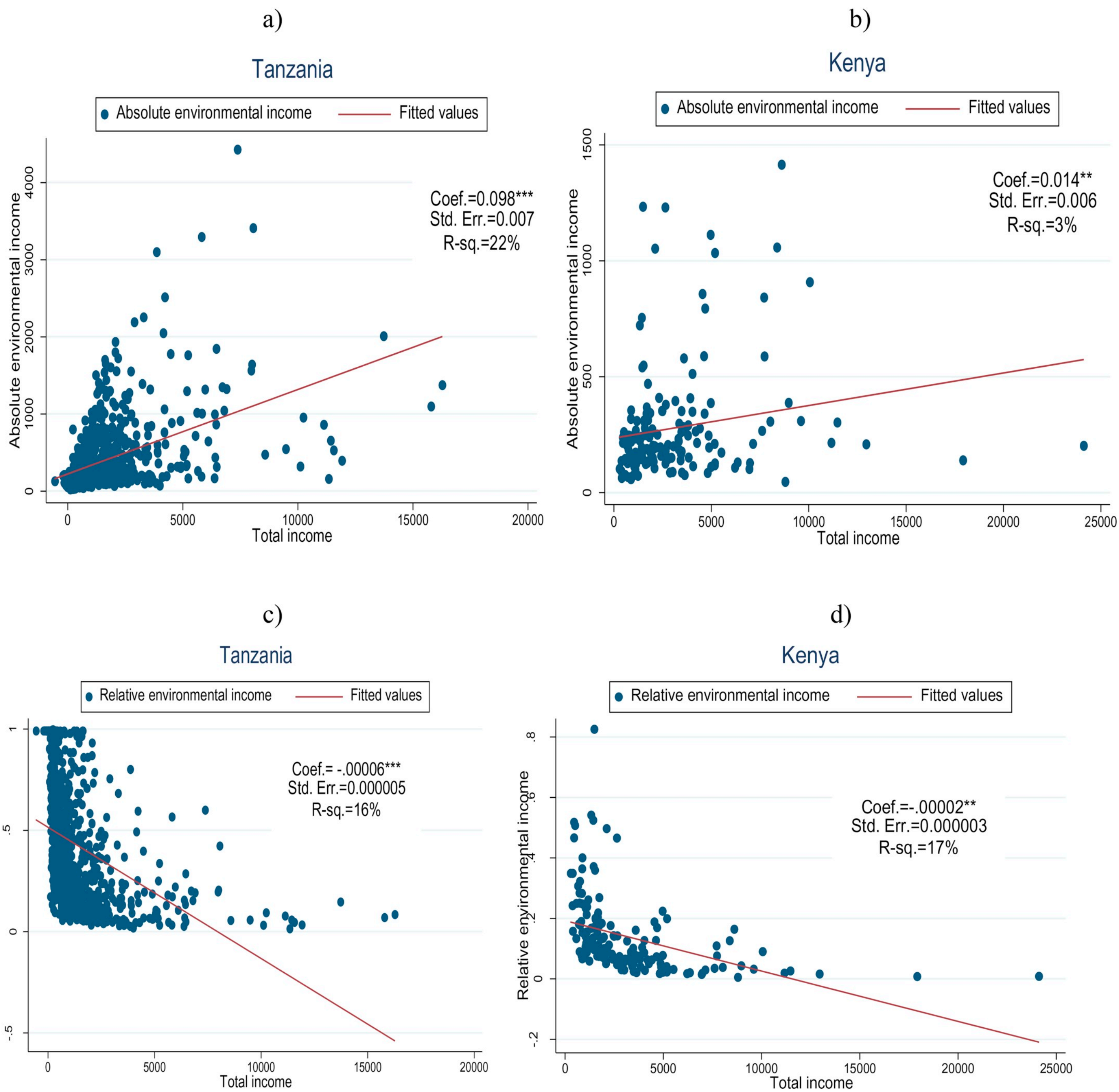
Appendix D (*continued*)

Income source	INC Q1		INC Q2		INC Q3		INC Q4		INC Q5	
	Abs[a]	Rel[b]	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel
Livestock income	358 (34)	47	695 (61)	47	1074 (107)	47	1747 (168)	47	3563 (419)	44
Business income	121 (26)	16	165 (30)	11	366 (82)	16	732 (161)	20	1158 (292)	14
Wage income	58 (20)	7	189 (51)	13	256 (60)	11	617 (141)	17	2169 (657)	27
Other income	50 (15)	6	122 (29)	8	243 (58)	11	314 (75)	8	849 (146)	10
Total income	770 (42)	100	1469 (33)	100	2284 (60)	100	3740 (88)	100	8148 (746)	100

Notes: Standard errors in parenthesis.

[a] Abs = absolute income (USD PPP).

[b] Rel = relative income (% of total income). For each income source and quintile, these are calculated as the share of the aggregated income in aggregated total income due to negative income sources incurred, thus no standard errors are reported.



Appendix E. The absolute environmental income and environmental reliance as functions of total income in Tanzania and Kenya

Appendix F

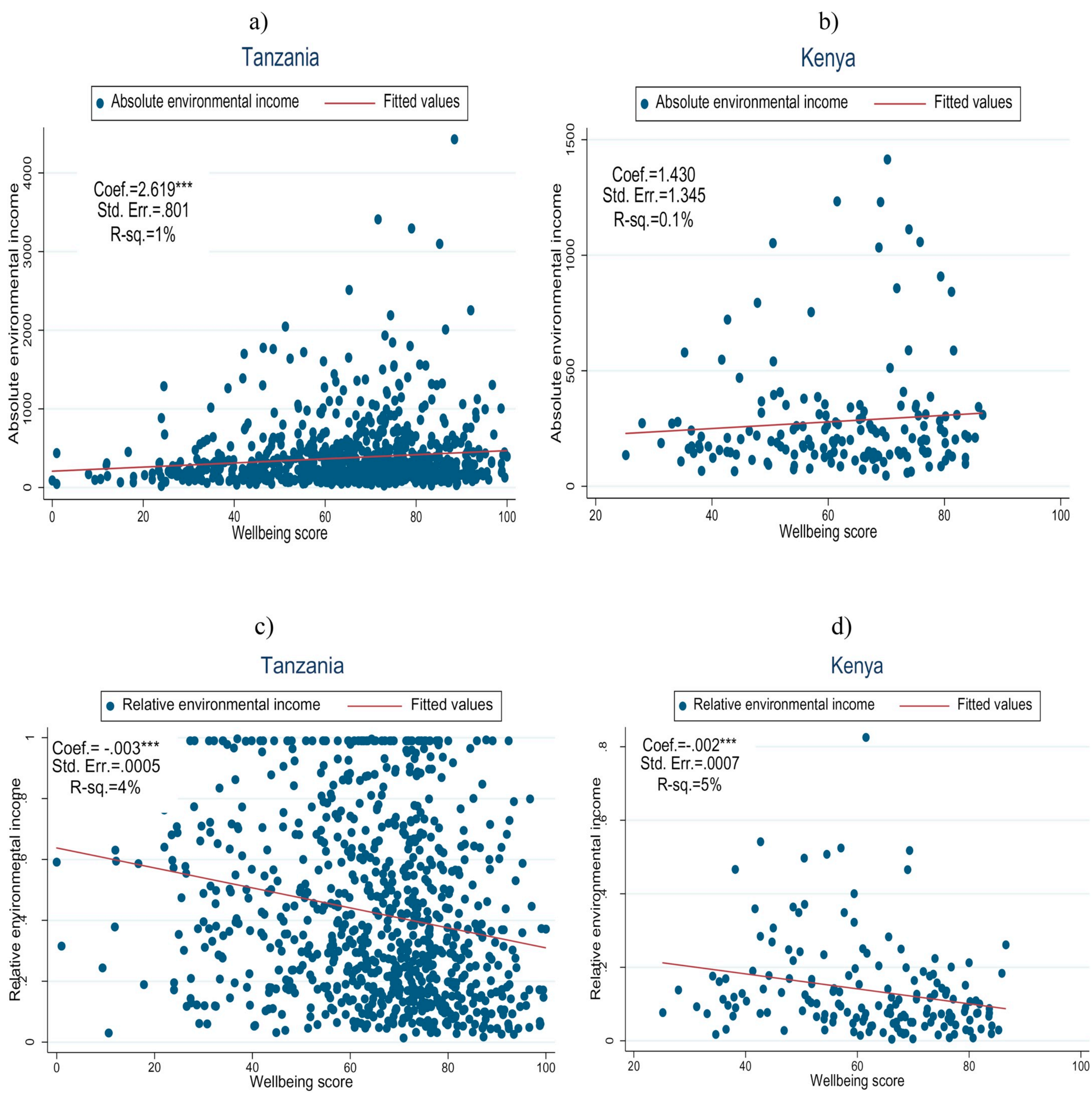
Annual total household income composition across income sources in absolute (USD PPP) and relative (%) measures (per adult equivalent unit) for well-being quintiles in Tanzania and Kenya

Income source	WB Q1		WB Q2		WB Q3		WB Q4		WB Q5	
	Abs[a]	Rel[b]	Abs	Rel	Abs	Rel	Abs	Rel	Abs	Rel
Tanzania (N = 825)										
Environmental income	320 (25)	37	354 (27)	30	357 (32)	25	427 (36)	29	433 (41)	20
Crop income	163 (30)	19	149 (21)	13	188 (33)	13	168 (39)	11	170 (41)	8
Livestock income	315 (47)	37	509 (150)	43	773 (152)	53	661 (98)	45	924 (128)	42
Business income	15 (4)	2	58 (29)	5	59 (14)	4	75 (20)	5	360 (89)	16
Wage income	33 (15)	4	75 (26)	6	52 (17)	4	117 (37)	8	276 (84)	13
Other income	14 (2)	2	26 (13)	2	16 (3)	1	16 (4)	1	35 (11)	2
Total income	860 (70)	100	1171 (170)	100	1445 (182)	100	1464 (128)	100	2198 (187)	100
Kenya (N = 159)										
Environmental income	249 (32)	13	273 (36)	13	236 (36)	8	384 (68)	9	262 (34)	5
Crop income	20 (19)	1	28 (19)	1	38 (25)	1	42 (38)	1	29 (24)	1
Livestock income	1040 (200)	53	1263 (206)	61	1595 (291)	56	1510 (259)	37	1966 (409)	37
Business income	232 (57)	12	211 (59)	10	614 (151)	21	688 (164)	17	780 (272)	15
Wage income	189 (80)	10	201 (72)	10	188 (58)	7	1025 (302)	25	1624 (605)	31
Other income	216 (53)	11	96 (32)	5	198 (48)	7	444 (106)	11	604 (141)	11
Total income	1945 (257)	100	2072 (224)	100	2869 (320)	100	4094 (523)	100	5266 (938)	100

Note: Standard errors in parenthesis.

[a] Abs = absolute income (USD PPP).

[b] Rel = relative income (% of total income). For each income source and quintile, these are calculated as the share of the aggregated income in aggregated total income due to negative income sources incurred, thus no standard errors are reported.



Appendix G. The absolute environmental income and reliance as functions of well-being score in Tanzania and Kenya

Appendix H
Pairwise comparison of total annual household income (USD PPP per adult equivalent unit) across income sources and income quintiles using ANOVA with Bonferroni test

Income source	INC Q1 vs INC Q2	INC Q1 vs INC Q3	INC Q1 vs INC Q4	INC Q1 vs INC Q5	INC Q2 vs INC Q3	INC Q2 vs INC Q4	INC Q2 vs INC Q5	INC Q3 vs INC Q4	INC Q3 vs INC Q5	INC Q4 vs INC Q5
Tanzania (N = 825)										
Environmental income	NS	***	***	***	NS	***	***	***	***	***
Crop income	*	***	***	***	NS	NS	***	NS	***	***
Livestock income	NS	NS	***	***	NS	**	***	NS	***	***
Business income	NS	NS	NS	***	NS	NS	***	NS	***	***

(continued on next page)

Appendix H (*continued*)

Income source	INC Q1 vs INC Q2	INC Q1 vs INC Q3	INC Q1 vs INC Q4	INC Q1 vs INC Q5	INC Q2 vs INC Q3	INC Q2 vs INC Q4	INC Q2 vs INC Q5	INC Q3 vs INC Q4	INC Q3 vs INC Q5	INC Q4 vs INC Q5
Wage income	NS	NS	NS	***	NS	NS	***	NS	***	***
Other income	NS	NS	NS	**	NS	NS	**	NS	NS	NS
Total income	NS	***	***	***	NS	***	***	***	***	***
Kenya (N = 159)										
Environmental income	NS	NS	NS	***	NS	NS	NS	NS	NS	NS
Crop income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Livestock income	NS	NS	***	***	NS	***	***	NS	***	***
Business income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Wage income	NS	NS	NS	***	NS	NS	***	NS	***	***
Other income	NS	NS	NS	***	NS	NS	***	NS	***	***
Total income	NS	**	***	***	NS	***	***	**	***	***

*, ** and *** signify statistical significance at 0.1, 0.05 and 0.01 levels, respectively. NS = not significant.

Appendix I

Pairwise comparison of total annual household income (USD PPP per adult equivalent unit) across income sources and well-being score quintiles using ANOVA with Bonferroni test

Income source	WBI Q1 vs WBI Q2	WBI Q1 vs WBI Q3	WBI Q1 vs WBI Q4	WBI Q1 vs WBI Q5	WBI Q2 vs WBI Q3	WBI Q2 vs WBI Q4	WBI Q2 vs WBI Q5	WBI Q3 vs WBI Q4	WBI Q3 vs WBI Q5	WBI Q4 vs WBI Q5
Tanzania (N = 825)										
Environmental income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Livestock income	NS	*	NS	***	NS	NS	NS	NS	NS	NS
Business income	NS	NS	NS	***	NS	NS	***	NS	***	***
Wage income	NS	NS	NS	***	NS	NS	**	NS	***	NS
Other income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total income	NS	*	*	***	NS	NS	***	NS	***	***
Kenya (N = 159)										
Environmental income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Livestock income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Business income	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Wage income	NS	NS	NS	**	NS	NS	**	NS	**	NS
Other income	NS	NS	NS	**	NS	*	***	NS	**	NS
Total income	NS	NS	**	***	NS	*	***	NS	**	NS

*, ** and *** signify statistical significance at 0.1, 0.05 and 0.01 levels, respectively. NS = not significant.

Appendix J

Cash and subsistence environmental incomes in absolute (USD PPP) and relative (%) per adult equivalent unit across regions and districts in the Greater Serengeti-Mara Ecosystem

	Cash environmental income		Subsistence environmental income	
	Abs[a]	Rel[b]	Abs	Rel
Southern	23.39 (6.38)	2.05	1018.73 (35.47)	97.95
Meatu district	23.80 (6.97)	2.42	916.48 (44.79)	97.58
Bariadi district	22.84 (11.70)	1.55	1156.50 (55.10)	98.45
Western	242.87 (67.06)	5.58	1804.76 (78.84)	94.42
Serengeti district	107.44 (33.40)	3.12	1810.81 (77.26)	96.88
Tarime district	517.16 (189.32)	10.56	1792.52 (180.62)	89.44
Eastern (Ngorongoro district)	117.65 (32.04)	3.21	2905.13 (129.70)	96.79
Ngorongoro Conservation Area	108.10 (42.27)	3.42	2303.43 (176.98)	96.58
Loliondo	123.69 (45.08)	3.08	3285.70 (171.15)	96.92
Northern (Narok county)	375.53 (96.60)	21.67	1360.53 (97.11)	78.33
All Sample	178.41 (29.86)	5.11	1724.93 (47.25)	94.89

Note: Standard errors in parenthesis.

[a] Abs = absolute income (USD PPP).

[b] Rel = relative income (% of total income). For each income source and quintile, these are calculated as the share of the aggregated income in aggregated total income due to negative income sources incurred, thus no standard errors are reported.

Appendix K

Frist and second stage regressions of 2SLS IV estimation for “Basic Material for a Good Life” well-being model using heteroskedasticity-based instrumental variables for environmental reliance in the Greater Serengeti-Mara Ecosystem, 2016–2017. The instruments were generated through the interaction between the demeaned (centered) regressors and the error term of the first stage regression (the environmental reliance regression model)

	First stage regression (Environmental reliance)	Second stage regression (Well-being sub-index on Basic material for a good life)
Environmental reliance	–	−0.774*** (0.118)
Household education (years)	−0.012*** (0.001)	0.054*** (0.007)
Female-headed household (0/1)	0.089*** (0.009)	−0.121 (0.078)
Age of household head (years)	−0.002*** (0.0002)	−0.0004 (0.002)
Shocks in the past 12 months (numbers)	−0.021*** (0.003)	−0.084** (0.025)
Distance to protected area (km)	−0.004*** (0.0004)	0.004 (0.003)
Tribe		
Maasai	−0.078*** (0.012)	0.390*** (0.103)
Sukuma	−0.030*** (0.010)	−0.323*** (0.089)
Kuria	−0.005 (0.011)	0.041 (0.097)
Country: Kenya	−0.210*** (0.013)	−0.574*** (0.113)
Instruments		
Household education (years) (centred)Xmodel residual	0.027*** (0.004)	–
Female-headed household (0/1) (centred)Xmodel residual	0.090*** (0.032)	–
Age of household head (years) (centred)Xmodel residual	0.003*** (0.001)	–
Shocks in the past 12 months (numbers) (centred)Xmodel residual	0.000 (0.010)	–
Distance to protected area (km) (centred)Xmodel residual	−0.007*** (0.002)	–
Maasai (centred)Xmodel residual	1.021*** (0.032)	–
Sukuma (centred)Xmodel residual	0.996*** (0.019)	–
Kuria (centred)Xmodel residual	0.963*** (0.030)	–
Kenya (centred)Xmodel residual	0.052 (0.070)	–
Constant	0.070*** (0.008)	0.071 (0.073)
Model statistics		
R-squared	0.883	0.200
Model significance (F(18, 966) and F(10, 966) for first and second stage regression, respectively)	414.43***	22.06***
Test of excluded instruments (F(9966))	640.67***	–
Sargan (overidentification test of all instruments, Chi-sqaured (8)		11.3612

References

Angelsen, A., Larsen, H.O., Olsen, C.S., 2011. Measuring Livelihoods and Environmental Dependence: Methods for Research and Fieldwork. Routledge, London.

Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N.J., Bauch, S., Börner, J., Smith-Hall, C., Wunder, S., 2014. Environmental income and rural livelihoods: a global-comparative analysis. World Dev. 64, S12–S28.

Babulo, B., Muys, B., Nega, F., Tollens, E., Nyssen, J., Deckers, J., Mathijs, E., 2008. Household livelihood strategies and forest dependence in the highlands of Tigray, Northern Ethiopia. Agric. Syst. 98, 147–155.

Babulo, B., Muys, B., Nega, F., Tollens, E., Nyssen, J., Deckers, J., Mathijs, E., 2009. The economic contribution of forest resource use to rural livelihoods in Tigray, Northern Ethiopia. Forest Policy Econ. 11, 109–117.

Baum, C.F., 2008. Stata tip 63: modeling proportions. Stata J. 8, 299–303.

Brown, T.A., 2006. Confirmatory Factor Analysis for Applied Research. Guilford Press, New York.

Butler, C.D., Oluoch-Kosura, W., 2006. Linking future ecosystem services and future human well-being. Ecol. Soc. 11, 30.

Cavendish, W., 2000. Empirical regularities in the poverty-environment relationship of rural households: evidence from Zimbabwe. World Dev. 28, 1979–2003.

Chao, F., Yunli, B., Linxiu, Z., Shuai, W., Xue, Y., 2018. Coupling conservation and livelihoods for sustainable management of protected areas in East Africa. J. Resour. Ecol. 9, 266–272.

Charlery, L., Walelign, S.Z., 2015. Assessing environmental dependence using asset and income measures: evidence from Nepal. Ecol. Econ. 118, 40–48.

Charnley, S., 2005. From nature tourism to ecotourism? The case of the Ngorongoro Conservation Area, Tanzania. Hum. Organ. 64, 75–88.

Conteh, A., Gavin, M.C., Solomon, J., 2015. Quantifying illegal hunting: a novel application of the quantitative randomised response technique. Biol. Conserv. 189, 16–23.

Debela, B., Shively, G., Angelsen, A., Wik, M., 2012. Economic shocks, diversification, and forest use in Uganda. Land Econ. 88, 139–154.

Dobson, A., 2009. Food-web structure and ecosystem services: insights from the Serengeti. Phil. Trans. R. Soc. B Biol. Sci. 364, 1665–1682.

Dokken, T., Angelsen, A., 2015. Forest reliance across poverty groups in Tanzania. Ecol. Econ. 117, 203–211.

Dublin, H.T., Ogutu, J.O., 2015. Population regulation of African buffalo in the Mara–Serengeti ecosystem. Wildl. Res. 42, 382–393.

Dybas, C.L., 2011. Saving the Serengeti-Masai Mara: can ecohydrology rescue a key East African ecosystem? BioScience 61, 850–855.

Ellis, F., 2000. Rural Livelihoods and Diversity in Developing Countries. Oxford University Press, Oxford.

Eriksen, S.H., Brown, K., Kelly, P.M., 2005. The dynamics of vulnerability: locating coping strategies in Kenya and Tanzania. Geogr. J. 171, 287–305.

Estes, A.B., Kuemmerle, T., Kushnir, H., Radeloff, V.C., Shugart, H.H., 2012. Land-cover change and human population trends in the greater Serengeti ecosystem from 1984–2003. Biol. Conserv. 147, 255–263.

Estes, A.B., Kuemmerle, T., Kushnir, H., Radeloff, V.C., Shugart, H.H., 2015. Agricultural expansion and human population trends in the greater Serengeti ecosystem. In: Sinclair, A.R., Metzger, K.L., Mduma, S.A., Fryxell, J.M. (Eds.), Serengeti IV: Sustaining Biodiversity in a Coupled Human-Natural System. The University of Chicago Press Press, Chicago, USA.

Gelman, A., Hill, J., 2006. Data Analysis Using Regression and Multilevel/Hierarchical Models. Cambridge University Press, Cambridge.

Gough, I., McGregor, I.A., Camfield, L., 2007. Theorizing wellbeing in international development. In: Gough, I., McGregor, I.A. (Eds.), Wellbeing in Developing Countries: From Theory to Research. Cambridge University Press, Cambridge.

Hampson, K., McCabe, J.T., Estes, A., Ogutu, J.O., Rentsch, D., Craft, M., Hemed, C.B., Ernest, E., Hoare, R., Kissui, B., Malugu, L., Masenga, E., Cleaveland, S., 2015. Living in the greater Serengeti ecosystem: human-wildlife conflict and coexistence. In: Sinclair, A.R., Metzger, K.L., Mduma, S.A., Fryxell, J.M. (Eds.), Serengeti IV: Sustaining Biodiversity in a Coupled Human-Natural System. The University of Chicago Press Press, Chicago, USA, pp. 607–645.

Holmern, T., Røskaft, E., Mbaruka, J., Mkama, S.Y., Muya, J., 2002. Uneconomical game cropping in a community-based conservation project outside the Serengeti National Park, Tanzania. Oryx 36, 364–372.

Jiao, X., Pouliot, M., Walelign, S.Z., 2017. Livelihood strategies and dynamics in rural Cambodia. World Dev. 97, 266–278.

Johannesen, A.B., 2005. Wildlife conservation policies and incentives to hunt: an empirical analysis of illegal hunting in western Serengeti, Tanzania. Environ. Dev. Econ. 10, 271–292.

Kalaba, F.K., Quinn, C.H., Dougill, A.J., 2013. Contribution of forest provisioning ecosystem services to rural livelihoods in the Miombo woodlands of Zambia. Popul. Environ. 35, 159–182.

Knapp, E.J., 2007. Who poaches? Household economies of illegal hunters in Western Serengeti, Tanzania. Hum. Dimens. Wildl. 12, 195–196.

Knapp, E.J., Rentsch, D., Schmitt, J., Lewis, C., Polasky, S., 2010. A tale of three villages: choosing an effective method for assessing poaching levels in western Serengeti, Tanzania. Oryx 44, 178–184.

Knapp, L.M., Knapp, E.J., Metzger, K.L., Rentsch, D., Beyers, R., Hampson, K., Schmitt, J., Cleaveland, S., Galvin, K.A., 2015. Human health in the greater Serengeti ecosystem. In: Sinclair, A.R., Metzger, K.L., Mduma, S.A., Fryxell, J.M. (Eds.), Serengeti IV: Sustaining Biodiversity in a Coupled Human-Natural System. The University of Chicago Press, Chicago, USA, pp. 679–699.

Lewbel, A., 2012. Using heteroscedasticity to identify and estimate mismeasured and endogenous regressor models. J. Bus. Econ. Stat. 30, 67–80.

MA, 2003. Ecosystems and Human Well-Being: A Framework for Assessment. Island Press, Washington, DC.
MA, 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.
Mamo, G., Sjaastad, E., Vedeld, P., 2007. Economic dependence on forest resources: a case from Dendi District, Ethiopia. Forest Policy Econ. 9, 916–927.
Masao, C.A., Makoba, R., Sosovele, H., 2015. Will Ngorongoro conservation area remain a world heritage site amidst increasing human footprint? Int. J. Biodivers. Conserv. 7, 394–407.
Mfunda, I.M., Roslash, E., 2010. Bushmeat hunting in Serengeti, Tanzania: an important economic activity to local people. Int. J. Biodivers. Conserv. 2, 263–272.
Møller, L.R., Smith-Hall, C., Meilby, H., Rayamajhi, S., Herslund, L.B., Larsen, H.O., Nielsen, Ø.J., Byg, A., 2018. Empirically based analysis of households coping with unexpected shocks in the Central Himalayas. Clim. Dev. 1–10.
Naidoo, R., Gerkey, D., Hole, D., Pfaff, A., Ellis, A., Golden, C., Herrera, D., Johnson, K., Mulligan, M., Ricketts, T., 2019. Evaluating the impacts of protected areas on human well-being across the developing world. Sci. Adv. 5, eaav3006.
Nielsen, M.R., Pouliot, M., Bakkegaard, R.K., 2012. Combining income and assets measures to include the transitory nature of poverty in assessments of forest dependence: evidence from the Democratic Republic of Congo. Ecol. Econ. 78, 37–46.
Nuno, A., John, F.A.S., 2015. How to ask sensitive questions in conservation: a review of specialized questioning techniques. Biol. Conserv. 189, 5–15.
Nuno, A., Bunnefeld, N., Naiman, L.C., Milner-Gulland, E.J., 2013. A novel approach to assessing the prevalence and drivers of illegal bushmeat hunting in the Serengeti. Conserv. Biol. 27, 1355–1365.
Oglethorpe, J., Ericson, J., Bilsborrow, R.E., Edmond, J., 2007. People on the Move: Reducing the Impacts of Human Migration on Biodiversity. World Wildlife Fund and Conservation International Foundation, Washington, DC.
PEN, 2007a. Pen Prototype Questionnaire Version 4. Poverty EnvironmentNetwork, CIFOR, Bogor.
PEN, 2007b. Technical Guidelines Version 4. Poverty EnvironmentNetwork, CIFOR, Bogor.
Rayamajhi, S., Smith-Hall, C., Helles, F., 2012. Empirical evidence of the economic importance of central Himalayan forests to rural households. Forest Policy Econ. 20, 25–35.
Reyes-García, V., Babigumira, R., Pyhälä, A., Wunder, S., Zorondo-Rodríguez, F., Angelsen, A., 2016. Subjective wellbeing and income: empirical patterns in the rural developing world. J. Happiness Stud. 17, 773–791.
Scoones, I., 1998. Sustainable Rural Livelihoods: A Framework for Analysis. IDS Working Paper 72. IDS, Brighton.
Scoones, I., 2015. Sustainable Livelihoods and Rural Development. Practical Action Publishing, Rugby, United Kingdom.
Sekar, N., Weiss, J.M., Dobson, A.P., 2014. Willingness-to-pay and the perfect safari: valuation and cultural evaluation of safari package attributes in the Serengeti and Tanzanian northern circuit. Ecol. Econ. 97, 34–41.
Sewando, P.T., Mutabazi, K.D., Mdoe, N.Y., 2016. Vulnerability of agro-pastoral farmers to climate risks in northern and Central Tanzania. Dev. Stud. Res. 3, 11–24.
Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B., Menkir, A., 2014. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: technological, institutional and policy options. Weather Clim. Extrem. 3, 67–79.
Silvestri, S., Zaibet, L., Said, M.Y., Kifugo, S.C., 2013. Valuing ecosystem services for conservation and development purposes: a case study from Kenya. Environ. Sci. Pol. 31, 23–33.
Summers, J., Smith, L., Case, J., Linthurst, R., 2012. A review of the elements of human well-being with an emphasis on the contribution of ecosystem services. Ambio 41, 327–340.
TEEB, 2010. Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB. UNEP.
URT, 2013. Population and Housing Census Counts 2012. National Bureau of Statistics. http://www.nbs.go.tz.
Vedeld, P., Angelsen, A., Bojö, J., Sjaastad, E., Berg, G.K., 2007. Forest environmental incomes and the rural poor. Forest Policy Econ. 9, 869–879.
Veldhuis, M.P., Ritchie, M.E., Ogutu, J.O., Morrison, T.A., Beale, C.M., Estes, A.B., Mwakilema, W., Ojwang, G.O., Parr, C.L., Probert, J., 2019. Cross-boundary human impacts compromise the Serengeti-Mara ecosystem. Science 363, 1424–1428.
Völker, M., Waibel, H., 2010. Do rural households extract more forest products in times of crisis? Evidence from the mountainous uplands of Vietnam. Forest Policy Econ. 12, 407–414.
Walelign, S.Z., Jiao, X., 2017. Dynamics of rural livelihoods and environmental reliance: empirical evidence from Nepal. Forest Policy Econ. 83, 199–209.
Walelign, S.Z., Pouliot, M., Larsen, H.O., Smith-Hall, C., 2017. Combining household income and asset data to identify livelihood strategies and their dynamics. J. Dev. Stud. 53, 769–787.
Wells, M.P., McShane, T.O., 2004. Integrating protected area management with local needs and aspirations. Ambio J. Hum. Environ. 33, 513–519.
Wenny, D.G., Devault, T.L., Johnson, M.D., Kelly, D., Sekercioglu, C.H., Tomback, D.F., Whelan, C.J., 2011. The need to quantify ecosystem services provided by birds. Auk 128, 1–14.
Winters, P., Corral, L., Gordillo, G., 2001. Rural livelihood strategies and social capital in Latin America: implications for rural development projects. In: Working Paper Series in Agricultural and Resource Economics, No. 2001–6. University of New England, Armidale, Australia.
Wittemyer, G., Elsen, P., Bean, W.T., Burton, A.C.O., Brashares, J.S., 2008. Accelerated human population growth at protected area edges. Science 321, 123–126.
Wunder, S., Angelsen, A., Belcher, B., 2014. Forests, livelihoods, and conservation: broadening the empirical base. World Dev. 64, S1–S11.
Yang, W., Dietz, T., Kramer, D.B., Chen, X., Liu, J., 2013a. Going beyond the millennium ecosystem assessment: an index system of human well-being. PLoS One 8, e64582.
Yang, W., Dietz, T., Liu, W., Luo, J., Liu, J., 2013b. Going beyond the millennium ecosystem assessment: an index system of human dependence on ecosystem services. PLoS One 8, e64581.
Yang, W., Dietz, T., Kramer, D.B., Ouyang, Z., Liu, J., 2015. An integrated approach to understanding the linkages between ecosystem services and human well-being. Ecosyst. Health Sustain 1, 1–12.